Cassini Attitude Control Software Testing: Performance Verification of a Deep Space Mission

Kevin J. Barltrop*
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
Mail Stop: 230-104
Phone: (818) 354-6412
Fax: (818) 393-4215
Kevin.J.Barltrop@jpl.nasa.gov

Larry Chang
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
Mail Stop: 230-104
Phone: (818) 354-????
Fax: (818) 393-4215
Larry.Chang@jpl.nasa.gov

Allan Y. Lee
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
Mail Stop: 230-104
Phone: (818) 354-4097
Fax: (818) 393-4215
Allan.Y.Lee@jpl.nasa.gov

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* Point of Contact

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Jet Propulsion Laboratory
California Institute of Technology

Extended Abstract

One of NASA's last highly redundant, self-sufficient deep space missions, the Cassini spacecraft and the attached Huygens probe roared into space atop a Titan 4B on October 15, 1997. With a busy four-year tour of Saturn and its moons, and numerous observations of opportunity along the way to Saturn, Cassini must satisfy stringent pointing performance requirements. To support the complex tour trajectory and the pointing demands of its instrument suite, the spacecraft must execute nearly flawless trajectory correction maneuvers and maintain a steady and accurate track on targets involved in complex motion. The capability to support these requirements comes together in the Cassini Attitude and Articulation Control Subsystem (AACS) flight software.

Paramount in the development and updating of the AACS flight system has been the need to perform comprehensive testing. In the spirit of the "test it as you fly it" philosophy, the testing must provide an accurate representation of the conditions under which the software will be used during the mission. The value of flushing out even minor problems though ground testing rather than in flight cannot be overstated. For the Cassini

mission, this strategy was implemented via a set of test beds supporting closed-loop simulation with and without hardware in the loop. For the specific purpose of confirming that the attitude control software meets its performance requirements, a collection of tests using software simulation of the spacecraft and the deep space environment were developed. These test cases are known collectively as the Cassini AACS Guidance and Control cases.

The test approach for the G&C cases starts with a collection of scenario descriptions covering a range of typical and mission-critical spacecraft scenarios. These scenarios include:

- spacecraft detumbling after spacecraft-launch vehicle separation
- sun search
- main engine and RCS thruster trajectory correction maneuvers
- Saturn orbit insertion
- Huygens probe release
- Huygens probe tracking
- low altitude radar mapping at Titan
- high precision imaging of science targets with the narrow angle camera
- reaction wheel momentum unloading
- data downlink to Earth

Each activity is reproduced as a nominal scenario along with numerous off-nominal variants. This provides a baseline confirmation that the mission requirements can be met, as well as insight into the margin available to accommodate extreme conditions. One engineer developed both the scenario definitions and the detailed test with peer review by an AACS team. Refinements to the tests were made as the mission progressed. Among other things, the detailed scenario descriptions document initial conditions, appropriate inertial properties selection, maneuver scenarios, predicted performance, relevant spacecraft requirements, and pass-fail criteria. Each test scenario is scripted for use in the Flight Software Development System (FSDS) to produce realistic command sequences in the presence of the various environmental and spacecraft model conditions. Hosted on Sun work stations, FSDS supplies a Sun™ workstation-based build of the flight software with the inputs need to simulate the physics and hardware of the spacecraft. Interactively or through scripts, a TCL command engine accepts the Cassini AACS spacecraft command set as well as special fault injection and environmental disturbance commands.

Each test activity focuses on key capabilities and environmental conditions. The trajectory correction maneuvers, for example, put the thrust vector control algorithm for the 445-Newton engine through its paces with intentional mismatches in onboard parameters. The low altitude radar mapping of Titan cases verify that Cassini can satisfy pointing requirements in the presence of external torque from various Titan atmospheric models and spacecraft control authority situations. The Probe Release cases verify that the release activity will not lead to any boom collisions or unexpected alarm conditions. In each case appropriate models have been developed to simulate the activity environment.

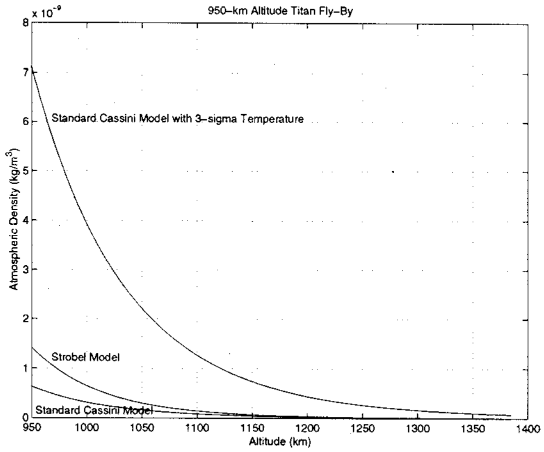

Figure 1. Titan Atmosphere Model

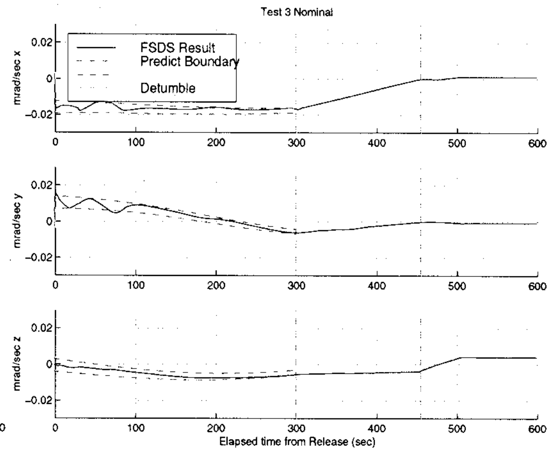

Figure 2. Huygen's Release

Verification of the test results comes through the analysis of simulation output with MATLAB scripts. The simulation results are presented to the test team in the form of statistical analyses and plots illustrated with pass threshold curves that are traced to Functional Requirements documents. Also, functional sanity checks are included to confirm that no red alarm conditions were detected by the fault protection system. Some test cases simulate stress situations that demonstrate the ability of the spacecraft to maintain control even under unrealistically stressful conditions.

Throughout the initial software development effort and continuing through the post-launch development phase, the G&C cases have provided an evolving resource for regression testing the flight software. Ongoing updates incorporate the latest environmental models and expand the range of activities and variants examined. For example, new cases based on improved Titan atmospheric density models, targeting with rotating coordinate system commands, new command sequence practices, and additional pointing constraint situations are under development to augment the current suite of tests. Where appropriate, some cases have been retired (launch scenarios for example).

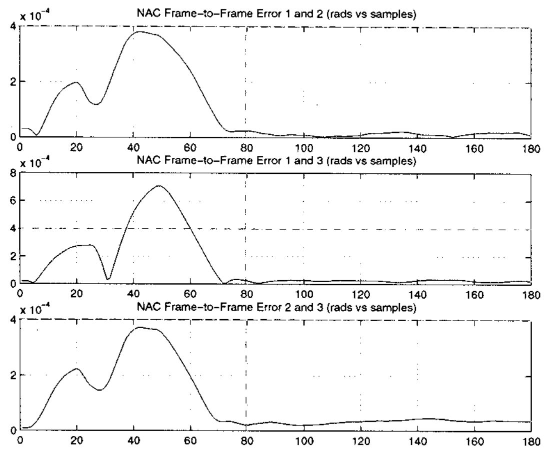

Figure 3. Point-to-Point Tracking Error

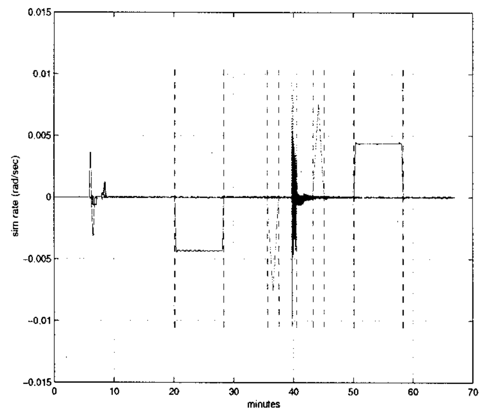

Figure 4. Main Engine TCM Turn Rates

In some cases, the test results can be compared directly to flight data collected later. This provides important assurance that the simulation fidelity is sufficient to generate confidence in the results of testing for future mission activities.

[Sample telemetry plots]

These test cases provided confirmation that the launch load would succeed in maintaining control of the spacecraft. Since launch, upgraded versions of the tests continue to verify that the latest software builds still satisfy the mission requirements. In addition, they provide useful predictions about the general behavior of the spacecraft, predictions that help the operations team assess the health and safety of the Cassini as it speeds towards its appointment with Saturn.